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Measurement of Time

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Watches are just one of many possible instruments of time measurement Time provides us with a **measure of change** by putting dates on moments, fixing the durations of events, and specifying which events happen before which other events. In order to do that, some method of time measurement is needed. The science or art of the accurate measurement of time is known as **chronometry** (or, less formally, **timekeeping**). A similar concept, **horology**, usually refers to mechanical timekeeping devices or timepieces. Time can be measured both in terms of the absolute moment when a particular event occurs, or in terms of a time interval, i.e. the duration of a continued event.

There are **two main methods** used in the everyday measurement of time, depending on the accuracy required or the interval covered. A clock is a physical mechanism that counts the ongoing passage of time, and is mainly used for more accurate timekeeping and for periods of less than a day. A calendar is a mathematical abstraction used for calculating more extensive periods of time (i.e. longer than a day). Typically, both methods are **used together** to specify when in time a particular events occurs (e.g. 12:30PM on 26 April 2019). Even before such methods were devised, mankind has always used more **informal methods** for basic timekeeping, such as the cycle of the seasons, and of day and night, and the position of the Sun in the sky.

Chronology, as opposed to chronometry, is the science of arranging events in their order or sequence of occurrence in time, and is mainly used for **studying the past**. For convenience, events can be put into chronological groups, a process known as periodization. Chronology, periodization and the interpretation of the past are together known as the study of **history**.

The measurement of time involves the use of various different units of measurement, depending on the time scales and periods under consideration. These range from the almost infinitesimal units employed in physics, though the everyday units (e.g. seconds, minutes, hours, days, months, years, etc.), to the much larger units used in geological and cosmological time scales.

Different time standards, specifications for the measurement of time, have been in use throughout history, although modern globalization and scientific internationalism have led to at the adoption of **highly accurate** and largely **universal** standards of time measurement and central reference points.

CLOCK

A **clock** is any free-standing device or instrument for measuring or displaying the current time. The English word "clock" comes from the Celtic words *clocca* and *clogan*, both meaning "bell". A **chronometer** is an exceptionally precise mechanical timepiece, designed to be accurate in all conditions of temperature, pressure, etc., especially one used at sea. **Watches** are sometimes distinguished from clocks in general, but really a watch is just a portable clock, usually worn in a pocket or on the wrist.

Really, a clock can be anything that **repeats** itself in a **predictable** way. The rotation of the Earth is a good example of something that is both repetitive and predictable, and indeed the turning of the Earth, as measured by the position of the Sun in the sky, was the first method mankind used to estimate the time of day. Other kinds of **clock mechanisms**, from the passage of water out of a vessel to the swinging of a pendulum to the vibration of a quartz crystal or the oscillation of a microscopic atom, are really just more manageable and more accurate variations on the same idea.

If the **principle** behind a clock is relatively simple, the **technological and engineering challenges** involved in building a clock of any accuracy are relatively complex, and much of the history of clocks in the last two millennia has revolved around the invention of more and more complex machines that are able to overcome the intrinsic problems of friction, temperature differences, movement, magnetic fields, size, etc., in search of the ultimate in accurate, reliable and practical timekeeping devices.

Division of Time

We use clocks to divide the day into smaller increments. Although a **10-hour clock** was briefly popular during **France**'s experiment with metric time measurement after the French Revolution, the **12-hour clock** – a convention dating back to ancient Egypt and Babylon – has continued to be the norm, along with **24-hour clocks** for some (mainly military and astronomical) applications. The standard **sexagesimal system** of time measurement – 60 minutes in an hour, 60 seconds in a minute – also owes its ancestry to the sexagesimal system used in Sumer and Babylonia from around 2000BCE, in which 60 was the base number for most mathematical and counting purposes.

Our present system of dividing the day and night into **24 equal hours** was instituted around the 14th Century. Prior to that, other than for some technical astronomical purposes, the day was usually split into 12 equal hours and the night into 12 equal hours, a practice dating back to ancient Egypt (although in practice, the night was often divided into 3 or 4 "watches" for security reasons). This meant of course that daytime hours were not necessarily of the same length as nighttime hours (except at the equinoxes), and hours at different times of the year would also vary in length. The advent of mechanical clocks institutionalized the use of 24 equal hours per day.
The first reference to clocks using 12 hours before noon and 12 hours after noon (all equal) comes from England in about 1380, although splitting the day into AM (**ante meridiem**, or before midday), and PM (**post meridiem**, or after midday) actually dates back to Roman days. The modern convention of starting the day at **midnight**, in the Roman style, is perhaps an arbitrary one, although a widely used one for all that, and the hour at which the day is considered to begin has varied throughout history and across different cultures. The ancient Greeks and Babylonians counted the day from sunset, as do orthodox Jews and Muslims even today; the Egyptians reckoned the hours from sunrise; in ancient Umbria the new day began at noon.

- **Ancient Clocks**

The clock is one of the oldest human inventions, and a bewildering array of **different mechanisms** have been employed over the millennia. The **sundial**, or **shadow-clock**, which measures the time of day by means of a shadow cast by the Sun onto a cylindrical stone, was widely used in ancient times, and can give at least a reasonably accurate reading of the **local solar time**. In a typical horizontal sundial, the Sun casts the shadow of a **gnomon** (a thin vertical rod or shaft) onto a horizontal surface marked with lines indicating the hours of the day. Some sundials may also be set vertically on the sides of buildings, and a wide variety of different designs have been employed over the centuries. As the Sun moves across the sky, the edge of the shadow aligns with the different hour markings. Sundials are therefore only of use during daylight hours, and when sufficient sun is shining, although in the Middle Ages an instrument called a **nocturnal** was developed which measured the nighttime hours according to the positions of the North Star or some other combination of stars (although again only when atmospheric conditions allowed).
Obelisks may have been used for shadow timekeeping in **ancient Egypt** as early as 3500BCE, but the first purpose-built sundials date from around 1500BCE, also in Egypt, and in **Babylonia** not too much later. The **ancient Greek**, **Roman** and **Chinese** civilizations all used sundials extensively, mainly based on earlier Egyptian and Babylonian designs.

The idea of using a gnomon parallel to the Earth's axis so that the hour lines indicate equal hours on any day of the year was first developed in the **Islamic Caliphate** in the 14th Century, and began to be used throughout **Europe** and elsewhere thereafter to give a better and more accurate reading of the time regardless of the seasons. Sundials were still being widely used as late as the 19th Century. Our use of time measurement units like minutes and seconds, which were originally radial angle measurements in geometry, probably arises from this method of measuring the time of day.

The **water clock**, or **clepsydra**, is, along with the sundial, probably the oldest time-measuring instrument. A simple water clock measures time by measuring the regulated flow of water into or out of a vessel of some sort. Water clocks existed in **ancient Egypt** and **Babylonia** at least as early as 1600BCE, and possibly significantly earlier in **India** and **China**, although the documentation is vague. Early water clocks were probably not very accurate, and even differences in ambient temperatures could result in significant errors. The **ancient Greeks** and **Romans** are usually credited with improving their accuracy by the use of complex gearing and **escapement mechanisms** (which transfer rotational energy into intermittent motions) around the 3rd Century BCE. They passed these designs on to **Byzantium** and the **Islamic world**, and thence back to **Europe**, although the **Chinese** also independently made similar improvements to their water clocks by about the 8th Century CE. Water clocks were usually calibrated using a sundial and, while never reaching a level of accuracy comparable to today's standards of timekeeping, they were the most accurate and commonly-used timekeeping devices for many centuries, until replaced by more accurate pendulum clocks in 17th Century Europe.

Candle clocks have also been used since antiquity, although it is difficult to establish any firm dates. A candle clock utilizes a slow-burning thin candle, with markings that indicate the passing of the hours as the candle burns down throughout the day (or night). A series of **sticks of incense** that burn down at a reasonably predictable speed were used in ancient Sparta, with each different smell denoting a particular hour of the day. In ancient China, the practice was to burn a knotted rope, noting the length of time required for the fire to travel from one knot to the next. Perhaps the most sophisticated candle clocks date from the **Islamic Golden Age** (12th – 13th Century).

The **hourglass** or **sandglass**, in which fine sand pours through a tiny hole at a constant rate, has long been used to indicate the passage of a predetermined period of time, even if it could not be used to tell the absolute time of day. Typically, an hourglass has two connected vertical glass bulbs, which allow a regulated trickle of sand (or sometimes crushed eggshell, which does not erode the glass as much) from the top to the bottom bulb. Once the top bulb is empty it can be inverted to begin timing again. Although the concept goes back to antiquity, the hourglass as we know it appears to have been invented in **medieval Europe**, and was in common use in the middle Ages, particularly on board ships.

- ## Mechanical Clocks

Mechanical clocks, governed by continually repeated mechanical ("**clockwork**") motion, began to be developed independently in **China**, the **Middle East** and **Europe** during the early middle Ages. They used a simple controlled release of power or **escapement mechanism** (a method of gradually and smoothly translating rotational energy into an oscillating motion that can be used to count time), as well as all manner of toothed wheels, ratchets, gears and oscillating levers. Early mechanical clocks were huge devices housed in church towers, and most early models still did not utilize a clock face or hands, but just struck the hour for religious and administrative purposes.

By the late 14th Century, the convention of a rotating hour hand on a fixed dial was adopted. Initially, accuracy was low, and errors of 15 minutes to an hour each day were common (minute hands were therefore not used). Gradually, though, these clocks began to acquire more and more extravagant features such as **automata** (moving figures) and complex **astronomical depictions** of the phases of the Moon, star maps, etc. The abbot of St. Alban's abbey, **Richard of Wallingford**, built a famous mechanical clock as an astronomical **ornery** (a mechanical model of the solar system) as early as about 1330. Another famous astronomical clock was built in Strasbourg in 1352.

Spring-driven clocks began to appear in the 15th Century in Europe, and gradually new innovations were developed in order to keep the clock movement running at a constant rate as the spring ran down. Once wound, a spring-driven clock conserves energy by means of a gear train, with a balance wheel regulating the motive force. Around 1500, Peter Heinlein, a locksmith in Nurnberg, Germany, began producing portable timepieces known popularly as "**Nurnberg eggs**". As accuracy increased (correct to within a minute a day), clocks began to appear with **minute hands** in the 16th Century, principally in **Germany** and **France**, one of the first being a 1577 clock made by **Jost Burgi** for the astronomer **Tycho Brahe**, who needed an accurate clock for his stargazing. However, minute hands only came into regular use around 1690.

By the time of the scientific revolution, clocks and their workings had become miniaturized enough for sufficiently wealthy families to share a personal clock, or perhaps even a pocket watch.

In 1656, the Dutch scientist **Christiaan Huygens** developed the **pendulum clock**, following earlier ideas of **Galileo,** who had discovered the **isochronism**, or constant period, of a pendulum's motion as early as 1583. The pendulum clock used a swinging bob to regulate the clock motion, achieving an accuracy of within 10 seconds per day. Such accuracy made the use of **minute hands** and even **second hands** a practical proposition. It had been known since 1644 that the period of a pendulum with a shaft length of precisely 0.994 meters (about 39.1 inches) had a **period** of precisely two seconds, one second for a swing in one direction and one second for the return swing. During the 17th Century, the center of clock-making production and innovation moved to **England** and, in 1670, **William Clement** created the **anchor escapement** as an improvement on the old **verge** (or **crown wheel**) **escapement**, which had been used since the 14th Century, and he also encased the pendulum in the classic long-case or "grandfather" clock.

In 1675, Huygens and **Robert Hooke** made another crucial advance with the **spiral balance**, or **hairspring**, to control the oscillating speed of the balance wheel. Englishman **Thomas Tompion** also successfully used this mechanism in **pocket watches** or **fob watches** (a fob is a pocket designed the hold a watch, or the chain or ribbon that attaches it). In 1761, another Englishman**, John Harrison**, made various improvements which allowed accurate clocks to be used at sea, an instrument known as the **marine chronometer**, which provided an important boost for navigation (the measurement of longitude requires an accurate knowledge of time). Harrison received a handsome £20,000 reward (equivalent today to around $4.5 million) from the British government for his solution to the intractable problem of longitude. **Second hands** began to be commonly added to long-case clock dials around 1780, and jewelled bearings to reduce friction and prolong the life of clockworks were introduced in the 18th Century. The **cuckoo clock** (containing a carved wooden bird that emerges and "sings" to tell the time) made its first appearance in the Black Forest region of **Germany** in the mid-17th Century, although the classic "chalet-style" cuckoo clock originated in **Switzerland** in the late 19th Century.

The accuracy and reliability of pendulum and spring-driven clocks, and their increasing cheapness and ubiquity, marked a big shift in everyday life in much of the developed world, as people moved from telling the time by natural signs or events to measuring it by the clock, with all the repercussions this had for work practices, productivity, industrial development, etc. Pendulum clocks continued to be widely used in the 18th and 19th Century, and **Switzerland** gradually established itself as the pre-eminent clock-making center during the 19th Century.

Alarm clocks have been around almost as long as clocks themselves. Some water clocks in classical times were adapted to strike an alarm, and some medieval mechanical clocks were also capable of chiming at a fixed time every day. Early user-settable mechanical alarm clocks, in which the alarm was set by placing a pin in the appropriate hole of a ring of holes in the clock dial, date back at least to 15th Century Europe. But the traditional mechanical wind-up alarm clock, that could be set for any time and was small enough to use on a bedside table, was patented by the American **Seth E. Thomas** in 1875.

Mass production of clocks with interchangeable parts began in the United States in the late 18th Century, and in 1836 the Pitkin brothers of Connecticut produced the first American-designed watch, and the first containing machine-made parts. New innovations and the economies of mass production, soon made the United States the leading clock-making country of the world, and competition reduced the price of a clock to $1 or less, so that for the first time most families could afford a clock. In 1884, at the International Meridian Conference, it was decided to place the **Prime Meridian** at Greenwich, England, establishing the international baseline of **Greenwich Mean Time (GMT)**.

Electric clocks, which wind the mainspring using an electric motor, first arrived in 1840, patented by Scottish clockmaker **Alexander Bain**, and were further developed commercially by an American, **Henry E. Warren**, in the early 1900s. By the end of the 19th Century, the invention of the **dry cell battery** made electric clocks a practical proposition, and mechanical clocks gradually came to be largely powered by batteries, removing the need for daily winding. By the 1930s, electric clocks were the most widely-used type of clock. Meanwhile, pocket watches began to be replaced by **wristwatches** after the First World War, when the success of wristwatches in military operations finally made them acceptable fashion accoutrements. The Swiss further developed their market dominance at this time through their mastery of the intricacies high quality wristwatches. The **British Broadcasting Company** began broadcasting its famous hourly time signal of six pips over the radio in 1924, allowing normal people to synchronize their watches with great accuracy.

- ## Modern Clocks

The development of electronics in the early decades of the 20th Century led to **electronic clocks** with no clockwork parts at all, with the timekeeping regulated by methods as varied as the vibration of a **tuning fork**, the piezoelectric behavior of **quartz crystals**, and even the quantum vibration of **atoms** of caesium or rubidium (all of which are however examples of **oscillatory motion**, the same general method as that employed by simple pendulum clocks).

The development of the **quartz clock** in the late 1920s finally made electronic clocks more accurate and reliable than pendulum clocks. Using vibrating quartz crystals as oscillators allowed the production of clocks that were accurate to a few ten-thousandths of a second per day. The advances in **microelectronics** in the 1960s, particularly in **Japan**, made quartz clocks both compact and cheap to produce, so that by the 1980s they had become the dominant timekeeping technology for both clocks and wristwatches. Even in the digital age, though, **Switzerland** has managed to retain its reputation for quality mechanical watches, although ironically more as prestige jewelry items and status symbols than as ultra-accurate timepieces.

Atomic clocks, which use the oscillation frequencies of the electromagnetic spectrum of atoms (principally caesium atoms) to regulate their timekeeping, are currently the most accurate clocks available (with an accuracy of around 10^{-9} seconds per day, or about 1 second in 316,000 years). Indeed, they keep time better and more consistently than the rotation of the Earth and the movement of the stars, and they have been used as primary standards for **international time distribution services** since the 1960s. A **hydrogen maser clock** at the US Naval Research Laboratory in Washington DC, which uses hydrogen atoms instead of caesium, is believed to be accurate to 1 second in 1.7 million years, currently the most accurate clock in use, although it is believed that super-cooled hydrogen maser clocks could reach accuracies approaching 1 second in 300 million years.

The electronic revolution of the 20th Century has also made possible **digital clocks**, which display a numeric representation of the time using LCD, LED or VCF displays, and **analog clocks** (with hands) have declined in popularity ever since. Digital clocks are now found on all computers, cellphones, etc., as well as on the **electronic timers** for central heating systems, ovens, VCRs, etc. Indeed, the youth of today are more likely to use their cellphone to tell the time than to wear a wristwatch. Many newer clocks and computer-based applications even reset themselves based on radio or **internet time servers** that are tuned to ultra-accurate atomic clocks. **Auditory clocks**, **tactile clocks** and **Braille watches** are also available for those with limited sight.

Satellite navigation systems like the **Global Positioning System (GPS)** require an unprecedentedly accurate knowledge of time. For example, a time error of just 1 microsecond can translate to a spatial error of about 300 meters. GPS signals are now provided directly from a network of 31 Earth-orbit satellites and linked to atomic clocks.

Atomic clocks and modern **time standards** (see the section on Time Standards) are able to keep incredibly precise time measurements consistent across the world. They are also able to account for the tiny and gradual changes needed to keep the time compatible with astronomical data. For example, the Earth's motion is slightly perturbed by the gravitational

attraction of the other planets, and there is a gradual shift in the orientation of Earth's axis of rotation (**precession**), so that the length of the tropical year is slowly decreasing: at the end of the 19th Century, the tropical solar year was 365.242196 days; at the end of the 20th Century, it was 365.242190 days. Also, **tidal friction** is gradually slowing the Earth's rotation, and lengthening the day by almost 2 milliseconds every century (so that, in a few hundred million years, a day will actually be 25 hours long), and large natural cataclysms like earthquakes and hurricanes can also have perceptible effects on the Earth's rotation.

The **Clock of the Long Now** is a recent project to design and build a mechanical clock that will function and keep accurate time for at least 10,000 years, and that will tell the time in a way that would be intelligible to any future civilization. While not as accurate as an atomic clock, it a good example of the long-term view of the importance of timekeeping that we humans are now starting to take.

Calendars

A calendar is a **system for organizing days** and specifying **dates**, as well as the physical device (whether paper or electronic) used to record such a system. Calendars have historically been designed for social, religious, agricultural, commercial or administrative purposes (or a combination of all of these). A calendar can also be extended into the future and used as a reminder of **future planned events**.

Calendar and Date Organization

Calendar divisions are based on the movements of the Earth and the regular appearances of the Sun and the Moon, and a calendar typically works by dividing time up into **units of days, weeks, months and years**. Most of these units are based on objectively verifiable **astronomical cycles**, although the use of **weeks** within calendars is purely for administrative convenience and is not tied to any astronomical cycle.

Any calendar system also needs to have a **starting or reference point**, sometimes referred to as a "**fiducial epoch**" (or just **epoch**), from which to begin counting. For example, the old Roman calendar used the assumed founding date of the city of Rome; the widely-used modern Gregorian calendar uses the supposed date of the birth of Christ; the Hebrew calendar uses the estimated date of the creation of the world; etc. A particular **date**, or the occurrence of a particular event, can then be specified with reference to these unit divisions and the starting reference point (e.g. 3rd of May 2013CE).

A variety of **standard date formats** are in use, differing in the order of date components, component separators, whether leading zeros are included, whether all four digits of the year are written, whether the month is represented numerically or by name, etc. The most commonly used date component sequence is the **little-endian** sequence day-month-year (e.g. 26/12/13), although the big-endian year-month-day is used in several Asian and European countries (e.g. 2013/12/26), and month-day-year is the norm in the United States and, usually, Canada (e.g. 12/26/13).

Types of Calendar

Almost all calendars divide up the days into months and years, but exactly how they do so varies. Most calendars synchronize their periods with the cycle of the **Sun** or **Moon** (or both), although some Ancient Egyptian calendars appear to have been synchronized to the motion of the planet **Venus** and/or the Dog Star **Sirius**. Because the period of the Moon does not neatly match the period of the Sun, no calendar can be truly based on both, and so a choice must be made, often incorporating periodic adjustments in order to match the two (a trade-off between accuracy and convenience).

The main types of calendar are:

- **Solar calendar** (e.g. the Persian Calendar, the Gregorian Calendar) is synchronized to the apparent motion of the Sun over the year and thus remains in line with annual seasonal changes. It makes no attempt to match the changes in the Moon, and the division into months is purely nominal.
- **Lunar calendar** (e.g. the Islamic Calendar) is synchronized to the phases of the Moon. Because a lunar month is not an even fraction of a year, a purely lunar calendar tends to drift against the seasons.
- **Luni-solar calendar** (e.g. the Hebrew calendar, the Hindu calendar) is based on a combination of both lunar and solar reckonings (i.e. months are based on lunar months, but years are based on solar years), in which most years have 12 months but every second or third year has 13 (including a leap month) in order to realign with the annual seasons.

Intercalation

The insertion of additional leap days or leap months into some calendar years in order to **synchronize** the calendar to the seasons or moon phases is called **intercalation** or **embolism**.
In the case of lunar and luni-solar calendars, the months (known as **lunar months** or **synodic months**) approximate the cycle of the Moon's phases, a period of about 29.5 days, for which many lunar calendars use alternating months of 29 and 30 days. However, because a lunar month is not an even fraction of a year (there are about 12.37 lunar months in a year), a purely lunar calendar tends to drift against the seasons unless adjusted periodically, such as by the addition of a **leap month** every two or three years.
In the case of solar calendars, the months are fractions of the **tropical or solar year** (i.e. the length of time the Sun takes to return to the same position in the cycle of seasons, as seen from Earth). Even with a solar calendar, though, the number of days in a year is not an exact whole number (approximately 365.242), so that a system of adding an extra **leap day** every fourth year (**leap years**) is instituted in many solar calendars, or more complex variations thereof.

Ancient Calendars

Ancient peoples used the apparent motion of the **celestial bodies** (the Sun, the Moon, the planets and the stars) through the sky to determine the seasons, the length of the month, and the length of the year. Many early civilizations developed calendars independently.

The **oldest known calendar** is a lunar calendar discovered near the town of Crathes in **Scotland**, which dates to around 8,000BCE. It consists of 12 pits in an arc 54 metres long that seem to correspond with 12 lunar months, plus an added correction to bring the calendar back into sync with the solar year on the date of the winter solstice. The megalithic standing stones of **Stonehenge** in southern England, begun around 3100BCE and rebuilt and added to many times over the succeeding 1,500 years, served various purposes, one of which was the determination of seasonal or celestial events, such as lunar eclipses, solstices, etc.

The **Sumerian calendar** is the earliest written calendar of which we have any evidence, dating back to as early as c. 3000BCE. The Sumerians used a luni-solar calendar, dividing the year into 12 lunar months of 29 or 30 days (for a total of 354 days), each beginning with the sighting of the new moon, plus an additional leap or intercalary month inserted as needed by decree of the priesthood, in order to synchronize with the 365-day solar year. The months were often referred to simply as "first month", "second month", etc, but also went by the names Nisanu, Aru, Simanu, Dumuzu, Abu, Ululu, Tisritum, Samna, Kislimu, Ṭebetum, Sabaṭu, Adar and Ve-Adar (the leap month).

The **Babylonians** carried on most of the ideas and knowledge of the Sumerians. They used a very similar luni-solar calendar to the Sumerians, with 12 lunar months plus an intercalary month inserted as needed. The Babylonians improved the overall accuracy of their calendar still further by using 12 years of 12 months followed by 7 years of 13 months, in a 19-year cycle. The artificial administrative concept of **weeks** was not introduced until the time of the late Babylonians and the **Chaldeans**, and they named the days after the Sun, Moon and the five known planets (the number seven was also widely held as auspicious by many ancient cultures, and enshrined in the creation myth of the Bible, thus assuring the legacy of the seven-day week).

The principal **ancient Egyptian calendar** was a solar calendar with a year that was 365 days long, divided into 12 months of 30 days each, with five extra festival days added at the end of the year. Prior to this system, the Egyptians used a lunar calendar but, realizing that it was not able to help predict important agricultural events like the annual flooding of the Nile, the Egyptians became the first to begin using a calendar based purely on the solar year.

In fact, for a period of over 2000 years, Egypt may have had three different calendars working concurrently: a stellar calendar for agriculture, a solar calendar of 365 days for civil administration, and a quasi-lunar calendar for festivals. Initially, the Egyptian solar calendar was not intercalated with leap days, and so astronomical events gradually varied in their incidence over the years. But in about 238BCE, Ptolemy III ordered that an extra day be added to every fourth year for increased accuracy, similar to the Julian leap year. The months were divided into three weeks of ten days each, and the year as a whole was divided into 3 seasons, *akhet* or Inundation (of the Nile), *peret* or Growth (Winter) and *shemu* or Harvest (Summer).

The **ancient Hebrew** or **Jewish calendar**, at least since the time of the Babylonian exile (538BCE) was a luni-solar calendar based on that used by the Sumerians and Babylonians, using twelve lunar months alternating between 29 and 30 days, with the addition of an intercalary month every two or three years to synchronize the lunar cycles with the longer solar year. The months were named Tishrei, Marcheshvan, Kislev, Tevet, Shevat, Adar, Nisan, Iyar, Sivan, Tammuz, Av and Elul (the intercalary month was referred to as Adar I), and the beginning of each lunar month was based on the appearance of the new moon. The starting point of Hebrew chronology is the year 3761BCE, the putative date of the creation of the world as described in the Old Testament.

The **ancient Mayan calendar**, along with those of other related Mesoamerican civilizations, were perhaps the most complex of all, and by some measures the most accurate, with an error margin of just 2 days over 10,000 years. They used two different parallel systems: the 260-day **Sacred Round**, and the 365-day **Vague Year**. The Sacred Round consisted of 13 numbered “months”, each of which contained 20 named days (Imix, Ik, Akbal, Kan, Chicchan, Cimi, Manik, Lamat, Muluc, Oc, Chuen, Eb, Ben, Ix, Men, Cib, Caban, Eiznab, Cauac and Ahau), and this was the calendar used for purposes such as naming individuals, predicting the future, deciding on auspicious days for battles, marriages, etc. Some other Mesoamerican cultures used a series of twenty 13-day *tricenas* instead. The Vague Year, on the other hand, consisted of 18 named “months” (Pop, Uo, Zip, Zotz, Tzec, Xuc, Yaxkin, Mol, Chen, Yax, Zac, Ceh, Mac, Kankin, Maun, Pax, Kayab and Cumku) of 20 numbered days each, with a five-day period at the end, known as Uayeb, which was considered unlucky. These two different cycles only coincided every 52 years, a period which was therefore considered in a similar way to modern centuries. The Maya fully expected to see history repeat itself every 260 years, after the full cycle of their calendar system.

The **ancient Chinese calendar** (or **Han calendar**) was a luni-solar calendar dating back to the Han Dynasty of the 2nd Century BCE, although similar luni-solar calendars had been in use there for almost a millennium by that time. It, or a version of it, is still used for civil purposes today in China, Japan, Korea, Vietnam, etc.

The Han calendar used 12 lunar months of 29 or 30 days with 7 intercalary months every 19-year cycle (similar to the entirely unrelated Babylonian system). Under this system, the Sun and Moon returned to their exact original relative positions after every 76 years. A reform in 1281 fixed the Chinese calendar at the equivalent of 365.2425 days, the same accuracy as the Gregorian calendar established in the West some three centuries later.

The **ancient Greek calendar** (also known as the **Attic** or **Athenian** calendar) was a luni-solar calendar, consisting of 12 named months of 29 or 30 days each (totalling 354 days), with a leap month added every third year to synchronize with the solar year. The months were named Hekatombaion, Metageitnion, Boedromion, Pyanepsion, Maimakterion, Poseideon, Gamelion, Anthesterion, Elaphebolion, Mounichion, Thargelion and Skirophorion, and were grouped into the familiar four seasons of summer, autumn, winter and spring. The additional leap month was achieved by repeating an existing month, so that the same month name was used twice in a row. However, there was also a "**conciliar calendar**", maintained parallel to the main "**festival calendar**", which divided the year according to the 10 (or later 11, 12 or 13) *phylai*, or sub-divisions of the Athenian population. Because of this variation over time, documents or events dated by this method are notoriously difficult to translate into modern calendar dates. A third, less official, calendar of seasons (using star risings to fix points in time) was also used for agricultural or maritime purposes.

The **Islamic calendar** was (and still is today) a lunar calendar consisting of 12 months alternating between 29 and 30 days, totalling 354 days in a year. The months are named Muḥarram, Ṣafar, Rabi' al-Awwal, Rabi' al-Thani, Jumada al-Awwal, Jumada al-Thani, Rajab, Sha'aban, Ramaḍan, Shawwal, Dhu al-Qi'dah and Dhu al-Ḥijjah. In each thirty year cycle, the 2nd, 5th, 7th, 10th, 13th, 16th, 18th, 21st, 24th, 26th and 29th years are leap years of 355 days. The Islamic calendar is used by Muslims to determine the proper days on which to observe Ramadan (the annual fast), to attend Hajj (pilgrimage to Mecca), and to celebrate other Islamic holidays and festivals. However, as a purely lunar calendar, the months tend to drift against the seasons (and with other solar-based calendars) so that it was not practical to used for agricultural purposes, and historically other calendars have been used for such purposes. Islamic years are counted from the Hijra in 622CE (the year when Muhammad emigrated from Mecca to Medina).

There were of course many other alternative calendars (e.g. **Gaulish**, **Hindu**, **Zoroastrian**, etc), each with their own underlying philosophy, and often with their own idiosyncratic twists and foibles. But the above-mentioned – along with the Roman calendar described below – are probably the most important and influential.

Roman, Julian and Gregorian Calendars

The earliest **Roman calendar** consisted of 304 days divided into 10 months (Martius, Aprilis, Maius, Iunius, Quintilis, Sextilis, September, October, November and December), with the winter days after the end of December and before the beginning of the following March not being assigned to any month. To account for these "unassigned" winter days, an additional two months, Ianuarius and Februarius, were added as a stop-gap measure by Numa Pompilius in the early 7th Century BCE, resulting in 12 lunar months of 29 or 30 days, totalling 355 days, with a leap month of 22 or 23 days, known as Mercdeonius or Intercalaris, added from time to time as dictated by the ruling Roman High Priest.

Roman years were dated from the founding of the city of Rome, which was originally assumed to be about 750BCE, although this date was later revised. However, both in everyday conversation and usually in official records, dates were commonly referred to according to the names of ruling **consuls**. Complications arose in this system because there were two consuls ruling at any one time, and because identical or similar names were common. The Romans initially used an eight-day week (based on its market cycle, and inherited from the Etruscans of antiquity) for commercial and administrative purposes, although as the empire expanded it encountered more and more cultures using the seven-day week, which it eventually adopted. The Romans also used a rather convoluted system of calculating the days of the month backwards from the publicly-declared fixed days of **Kalends** (1st day of the month), **Nones** (5th or 7th day of the month, depending on the particular month's length) and **Ides** (13th or 15th day of the month).

Later, when these conflicting and confusing systems became completely inoperable, the Roman calendar was drastically overhauled, on the advice of the Greek astronomer **Sosigenes**, by **Julius Caesar** during his third consulship in 46BCE, reforms that were completed by **Augustus** two years later. The resulting **Julian calendar** became the predominant calendar throughout most of Europe (as well as some Muslim countries), until superseded by the **Gregorian calendar** in 1582. The Julian calendar was a solar calendar consisting of a regular year of 365 days divided in to 12 months, with a leap day added in February (Februarius) every four years. The month names were the same as the earlier Roman calendar, although the lengths of the months were adjusted to the 30 and 31 day months (with a rogue 28/29 day month in February) we are familiar with today.

Although the Julian calendar was widely used throughout the Middle Ages, different countries still used various local systems to count or identify years. These were usually **regnal years**, based on the reign of a particular sovereign or leader, in the Biblical fashion, although cyclical events (e.g. the 4-year Greek Olympiads, the 12-year Chinese animal cycle, etc) were used in some cases.

Individual days of the year were usually indicated in relation to one of the church feasts, e.g. the 4th day after Easter in the 6th year of the reign of King xxxxx. To replace this rather awkward system, the Christian monk **Dionysius Exiguus** in the 6th Century, introduced the **Anno Domini** (AD) system of counting years from the putative (probably erroneous) birth of Christ. The new system caught on only gradually and was not widely used until the 11th to 14th Century, and the use of the BC sequence, counting backwards from the birth of Christ, was not introduced until as late as the 17th Century. The lack of a year zero (the year before AD1 is 1BC) and the awkward necessity of counting backwards for dates BC (before Christ) were drawbacks to this system, but it has nevertheless remained a much more popular reference point than other proposed alternatives, such as the **Byzantine** church's use of the creation of the world (which they calculated to be 5509BC), or the **Jewish** creation date (calculated as 3761BC). The more recent (non-religious, and more politically correct) use of CE and BCE, using the abbreviations for **Common Era** (or **Current Era** or **Christian Era**) and **Before Common Era** instead of AD and BC, has not changed that reference date, which has now become the *de facto* standard worldwide.

The **Gregorian calendar** (also sometimes referred to as the **Western calendar** or **Christian calendar** or **New Style calendar**) was a minor refinement to the Julian calendar, introduced by **Pope Gregory XIII** in 1582, based on a proposal by **Aloysius Lilius**. The Julian year, with its leap year every four years, was still 11 minutes 14 seconds longer than the exact solar year on average, and this error had been accumulating for centuries. The Gregorian calendar reform reduced the number of leap years, so that years divisible by 100 (that would otherwise be leap years) were now not to be considered leap years, unless the year was also divisible by 400. This had the effect of correcting the length of a year from 365.25 days to a more accurate 365.2425 days, so that, while the Julian calendar carried forward an error of about 11 minutes each year, the Gregorian calendar was accurate to within just 2.6 seconds a year. This is accurate enough that an extra leap day to compensate for accumulating errors will not be needed until about the year 4000. The 1582 reform also dealt with the cumulative effect of the 11-minute Julian calendar errors (dating back to the First Council of Nicaea in 325CE) by completely skipping the 10 days from 5th to 14th October in the year 1582.

Although many Protestant and Eastern Orthodox countries continued to use the old Julian calendar for a time, the Gregorian calendar was slowly adopted throughout Europe (when the Gregorian calendar was finally adopted in Britain in 1752, for example, an 11-day correction needed to be made to account for further accumulated errors). Most branches of the Eastern Orthodox Church still use the Julian calendar (or the **Revised Julian calendar**) for calculating the dates of their moveable feasts, like Easter, and it is still used by the Berber people of North Africa. The Gregorian calendar, though, is now used throughout most of the Western world as well as in many parts of Asia, and it has become the unofficial global standard, recognized by most international institutions, including the **United Nations**.

Various “improvements” to the Gregorian calendar system have been proposed over the years, such as **Marco Mastrofini**’s proposed **World Calendar** or **Moses Cotsworth**’s **International Fixed Calendar**, but none have ever gained enough traction to merit the huge administrative inconvenience involved.

Periodization

When dealing with time scales longer than those usually measured by calendars and clocks, the longer-term past can be divided up into convenient periods or blocks of time in a process known as **periodization**. Although records exist for most of human history, for longer time scales we must rely on geological and paleontological dating techniques.

To some extent, the start and end of identified periods is necessarily somewhat arbitrary (or at least imprecise), and periods may even overlap. But grouping together periods of time with relatively stable characteristics does provide at least some sort of **framework** to help us understand what would otherwise be a continuous stream of scattered and apparently random events.

Human Time Scale

The labels used for periodization of the more recent past may utilize many **different references**, including:

- **Calendar dates** (e.g. the 1960s, the 17th Century, etc.);
- **Prominent individuals** (e.g. the Victorian Age, the Napoleonic Era, etc.);
- **Historical or political events** (e.g. the post-War years, the pre-Columbian Era, etc.),
- **Cultural movements** (e.g. the Renaissance, the Romantic Period, etc.).

Some usages are necessarily **geographically specific** (e.g. the Meiji Era of Japan, the Merovingian Period of France, etc.), and cultural references in one part of the world may be at odds with those in other parts (e.g. the Italian Renaissance of the 14th to 16th Century, the English Renaissance of the 16th and 17th Century, the Harlem Renaissance of the 1920s, etc.). Some periods may even be entirely **illusory** or **mythological** in nature (e.g. the Golden Age, the Age of Aquarius).

The periodization of **human prehistory** typically relies on changes in material culture and technology (e.g. the Stone Age, the Bronze Age, the Iron Age, etc.). Within these broad general periods, sub-periods can be identified (e.g. the Stone Age can be divided up into the Paleolithic, Mesolithic and Neolithic Periods; the Bronze Age is sometimes split into the Copper and the Bronze Age; etc.). It relies to a large extent on dating techniques such as **radiocarbon dating** (which is quite accurate within a range of 500 to 50,000 years), and other even longer-scale **radiometric dating** techniques.

Geological Time Scale

Further back into pre-human history, in what is sometimes referred to as "**deep time**", there are no human or archaeological markers to use, and geologists, paleontologists and earth scientists use the **geological time scale** (or **geologic time scale**). This time scale splits up periods of the magnitude of many millions of years, utilizing geological and paleontological techniques like **stratigraphy** (the study of rock layers) and the fossil record of major events like **mass species extinctions**. The concept of geological time had its beginnings with the ground-breaking work of the early geologist **James Hutton** in the 18th Century, who was the first to realize that the Earth must be many millions of years old, not just the few thousands of years maintained by theologians. Hutton's early work was supported in the 19th Century by fellow Scot **Charles Lyell**, and later still by **Charles Darwin**.

The geologic time scale is usually divided up as follows:

- **eons** and **supereons –** broad timespans (rarely used) covering half a billion years or more, e.g. Hadean Eon, Achaean Eon, Proterozoic Eon, Phanerozoic Eon.
- **Eras** – intermediate timespans of several hundred million years, e.g. the Phanerozoic Eon is split into the Paleozoic, Mesozoic and Cenozoic Eras.
- **Periods** – intermediate timespans of tens or hundreds of millions of years, e.g. the Mesozoic Era is split into the Triassic, Jurassic and Cretaceous Periods.
- **Epochs** – shorter timespans of tens of millions of years, e.g. the Early, Middle and Late Jurassic Epochs.
- **Ages** – even shorter timespans (also rarely used, apart from in highly technical circumstances) typically covering a few million years each, e.g. Hettangian, Sinemurian, Pliensbachian, etc.

Cosmological Time Scale

Outside of these time scales, and beyond even the age of the Earth, the **cosmological time scale** applies, using the **Big Bang** (the creation of the universe itself) as a reference point. Physicists have been able to model the time after the Big Bang with remarkable accuracy (see the section on Time and the Big Bang), and have identified various "**epochs**" depending on the ambient temperature of the universe and the physical phenomena that arose:

- **Planck Epoch** – the first 10^{-43} seconds after the Big Bang, theoretically the smallest time period it would ever be possible to measure, and about which we absolutely nothing.
- **Grand Unification Epoch** – 10^{-43} to 10^{-36} seconds after the Big Bang.
- **Inflationary Epoch** – 10^{-36} to 10^{-32} seconds.
- **Electroweak Epoch** – 10^{-36} to 10^{-12} seconds.
- **Quark Epoch** – 10^{-12} to 10^{-6} seconds.
- **Hadron Epoch** – 10^{-6} seconds to 1 second.
- **Lepton Epoch** – 1 to 10 seconds.
- **Photon Epoch** – 10 seconds to about 380,000 years.
- **Reionization Epoch** – about 150 million to about 1 billion years after the Big Bang.

In *The Five Ages of the Universe*, a popular science book by **Fred Adams** and **Gregory Laughlin**, the evolution of the universe, from the deep past to the deep future future, is split into five ages or **eras** (also see the section on Time and the Big Bang):

- **Primordial Era** – from the Big Bang to about 350,000 years, or, in terms of orders of magnitude, up to about 10^5 years.
- **Stelliferous Era** – stars and galaxies are formed, from 10^6 to 10^{14} years.
- **Degenerate Era** – stars gradually burn out and die, from 10^{15} to 10^{39} years.
- **Black Hole Era** – black holes dominate, but gradually start to break down and evaporate, from 10^{40} to 10^{100} years.
- **Dark Era** – only random, isolated, low-energy particles remain, after 10^{100} years.